COMPARED PERFORMANCES OF MICROWAVE PASSIVE SOIL MOISTURE RETRIEVALS (SMOS) AND ACTIVE SOIL MOISTURE RETRIEVALS (ASCAT) USING LAND SURFACE MODEL ESTIMATES (MERRA-LAND)

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ABSTRACT— Performances of two global satellite-based surface soil moisture (SSM) retrievals with respect to model-based SSM derived from the MERRA (Modern-Era Retrospective analysis for Research and Applications) reanalysis were explored in this paper: (i) Soil Moisture and Ocean Salinity (SMOS; passive) Level-3 SSM (SMOSL3) and (ii) the Advanced Scatterometer (ASCAT; active) SSM. Temporal correlation was used to investigate the performance of SMOSL3 and ASCAT SSM products during the period 05/2010–2012 on a global basis. Both SMOSL3 and ASCAT (slightly better) captured well (R>0.70) the long-term variability of the modelled SSM, particularly, over the Indian subcontinent, the Great Plains of North America, and the Sahel. However, ASCAT had negative correlations in arid regions, in particular across the Sahara and the Arabian Peninsula. This may be due to complex scattering mechanisms over very dry surfaces. To explore the land cover dependence of the analyzed statistical indicators, the global correlation results were averaged per biome extracted from a global map of biomes. In general, SMOSL3 and ASCAT performances behaved differently from one biome to another. For SMOSL3, the highest average correlation was observed over "tropical semi-arid" (R=~ 0.5) and "temperate semi-arid" biomes, whereas for ASCAT, the highest correlations were observed over "tropical semi-arid" (R=~ 0.7) and "tropical humid" biomes. The poorest agreement for both SMOSL3 and ASCAT was generally found over "tundra" and "desert temperate" biomes, particularly for ASCAT. This study showed that the performance of both SMOSL3 and ASCAT is highly dependent on vegetation. We also showed that both of them provide complementary information on SSM, which implies a potential for data fusion which would be pertinent for the ESA climate change initiative (CCI).

Index Terms—Soil moisture, ASCAT, SMOS, biomes

1. INTRODUCTION

Soil moisture (SM) is a key component in the hydrologic cycle processes, as it plays a major role in the exchange of water and heat between the atmosphere and the land surfaces [1-3]. Knowledge about the global spatio-temporal variability of SM is important to improve our understanding of the interactions between the land surface (including hydrosphere and biosphere) and the atmosphere.

Remote sensing active and passive microwave satellite observations can be used to directly derive global surface SM (SSM) products [4-8], readers are directed to [9] for a detailed review. These, amongst others, include: 1) the Soil Moisture and Ocean Salinity (SMOS) SSM products and 2) the advanced scatterometer (ASCAT) SSM products.

SMOS is a passive satellite that was launched in November 2009, which operates at L-Band (1.4 GHz), with the purpose to measure SSM on a global scale [10] with an average spatial resolution of 43 km. SSM products are retrieved from SMOS brightness temperatures measurements at the CATDS Centre (Centre Aval de Traitement des Données), and provided as level 3 global gridded maps (SMOSL3; [11]), using multi-orbit retrievals [12].

The ASCAT scatterometer is an active sensor operating on-board the Metop satellite since 2006 at a C-band (5.25 GHz). Vienna University of Technology (TU-Wien) developed a change detection algorithm to retrieve SSM products from ASCAT backscatter measurements [13].

SMOS and ASCAT have been extensively inter-compared and validated in different regions of the world using ground based measurements (e.g., [14-17]) and model simulations as benchmarks [18-20].

However, the aforementioned studies relied mostly on the old versions of SMOS and ASCAT SSM products, and mostly for the year 2010. In this study, we investigated the performances of SMOS and ASCAT SSM products, globally, using the latest released SSM products, against land surface SSM simulations (MERRA-Land) for the period 05/2010–12/2012. MERRA-Land, developed from MERRA (Modern-era Retrospective analysis for Research and Ap-

plications) reanalysis by the National Aeronautics and Space Administration (NASA), SSM product was validated extensively against ground based measurements and it was shown to have good spatial and temporal performances (e.g., [21, 22]).

The aim of this study is to understand the spatio-temporal variability of SMOS and ASCAT SSM over a variety of biomes at the global scale.

2. MATERIALS AND METHODS

2.1 Datasets
2.1.1. SMOSL3 Level 3 soil moisture
A new re-processed level of SMOS SSM product was released by the CATDS Centre i.e. SMOS level 3 products (SMOSL3), which is provided as global gridded maps of SSM. This product is an improved and filtered version of the preceding standard level i.e., SMOS Level 2, produced by the ESA algorithm, wherein the quality of the SSM products is enhanced by using multi-orbit retrievals in SMOSL3 [11]. SMOSL3 SSM products are provided with ascending overpass at 0600 Local Solar Time (LST) and descending overpass at 1800 LST [10]. The ascending retrievals were used in this study [23].

2.1.2. ASCAT soil moisture
ASCAT SSM products, derived from the ASCAT backscatter observations, are provided with ascending overpass at 21:30 Local Solar Time (LST) and descending overpass at 09:30 LST. Only descending overpasses were considered in this study, as for SMOSL3 (e.g., [24]). The latest SSM products (WARP5.5) available from ASCAT were used in this study.

2.1.2. MERRA-Land soil moisture
MERRA-Land is a supplemental product for MERRA reanalysis, which includes hydrological variables [22]. It is a replay of a revised version of the MERRA land model component. The precipitation forcing was corrected in MERRA-Land by merging MERRA precipitation with gauge-based data products, from the NOAA Climate Prediction Centre. The gridded SSM products, at soil depth of 0–2 cm, were used in this study.

2.2 Pre-processing and methods
Both the ASCAT and SMOSL3 SSM dataset were screened out using associated flags before the comparison:
- (i) ASCAT noise error > 14% [25]
- (ii) SMOSL3 Data Quality indeX (DQX) and Radio Frequency Interferences (RFI) > 0.06 and > 30%, respectively
- (iii) Topographic complexity > 10% [25]
- (iv) Water bodies > 5%.

Next we re-projected all the three datasets, using a nearest neighbor approach, onto a common regular 0.25° x 0.25° grid [26].

The Pearson correlation coefficient (R) was computed for all common pixels between the MERRA-Land and the two remotely sensed SSM products, using the original SSM values.

To analyse the effects of vegetation on the SSM retrievals we computed the average of the global correlation values for both ASCAT and SMOSL3 as a function of land cover (biomes) according to the global distribution of major biomes produced by [27], which is displayed in Fig. 1.
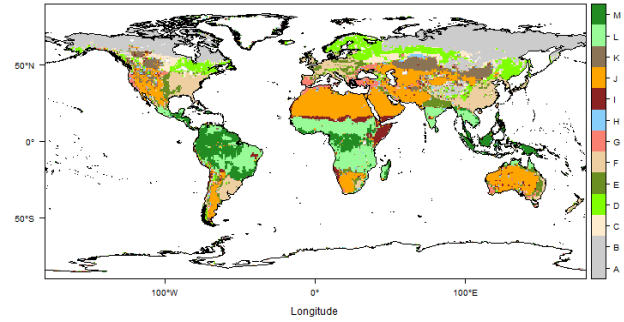

Fig. 1 Distribution of world biomes (A & B = Tundra C=Boreal semi-humid, D = Boreal humid, E= Temperate semi-arid, F= Temperate humid, G= Mediterranean warm, H =Mediterranean cold, I=Desert tropical, J=Desert temperate, K= Desert cold, L= Tropical semi-arid, and M=Tropical humid), adapted from [27]

3. RESULTS

Global maps of the calculated correlation coefficient between SMOSL3 (top panel) and ASCAT (bottom panel) original SSM values, with only significant correlations (i.e. p-value < 0.05), against the reference dataset (MERRA-Land) at each pixel over the 05/2010–12/2012 period are displayed in Figs. 2.

There is a general similarity of the spatial patterns over most of the globe for both SMOSL3 and ASCAT with strong correlation (R>0.5) between the SMOSL3 and ASCAT and the reference SSM products in the transition zones between wet and dry climates (e.g., Sahel), in the Great Plains (USA), Western Europe, Australia, India, Kazakhstan, and the south-eastern region of Brazil. Strong seasonal cycles of SSM explain these high values of R in these regions [28].
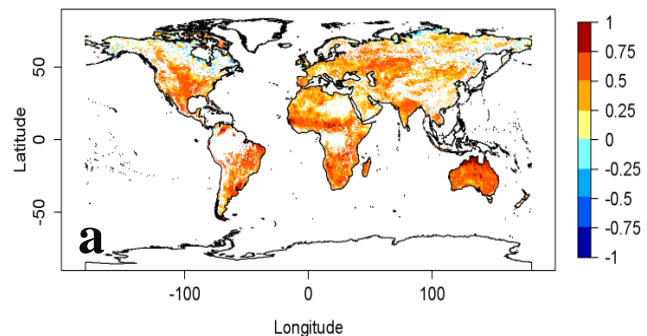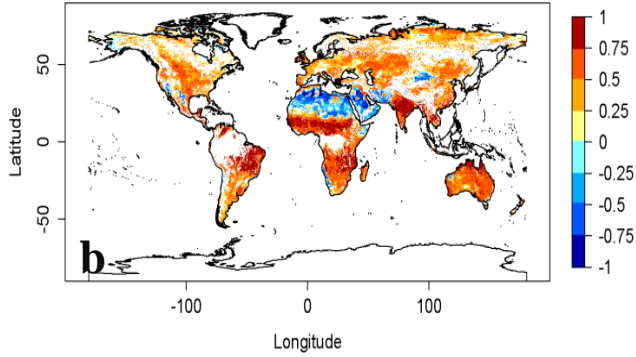
Fig. 2 Global correlation coefficient between MERRA-Land and SMOSL3 (a) and ASCAT (b) for the 2010-2012 period. Only significant correlations (p<0.05) were plotted.

However, weak correlations (R < 0.15) and negative values of R for ASCAT (e.g., Saudi Arabia, North Africa) can be seen over desert areas and over high latitude regions. In these later regions, the small range of variation in the SSM values may explain the low values of R, which corresponds to the remotely sensed retrieval accuracy (~ 0.04 m³/m³). Systematic errors in the change detection algorithm are good candidates to explain the negative correlation between the ASCAT and MERRA-Land SSM products [13].
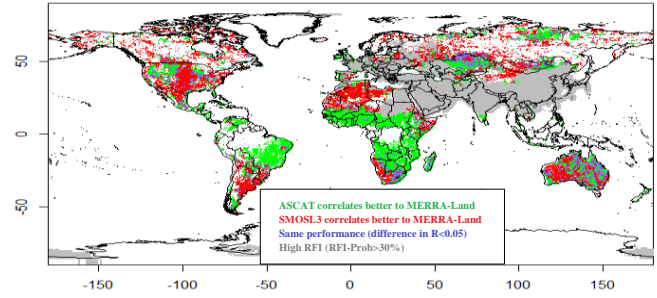

Fig. 3 Global map of correlations: ASCAT correlates better to MERRA-Land (in green), SMOS correlates better to MERRA-Land (in red), same performance (difference in R<0.05, in blue), and high RFI (3 year average of RFI-Prob>30%, in grey).

A different insight in these results was provided by accounting for different biomes as shown in Fig. 4. Fig. 4 shows that the performance (in terms of R) of SMOSL3 and ASCAT is strongly related to the distribution of the biomes. The values of the correlation coefficient (R > 0.5) are highest for both ASCAT (slightly higher) and SMOSL3 over tropical semi-arid and lowest (R) over tundra regions.

With the exception of boreal and tundra regions, correlation values for ASCAT vary strongly from one biome to another from R~0.50 over tropical humid to R~0.1 over desert temperate biomes, whereas for SMOSL3 values of the correlation coefficient (R ~ 0.4) remain relatively constant for most of the biomes.
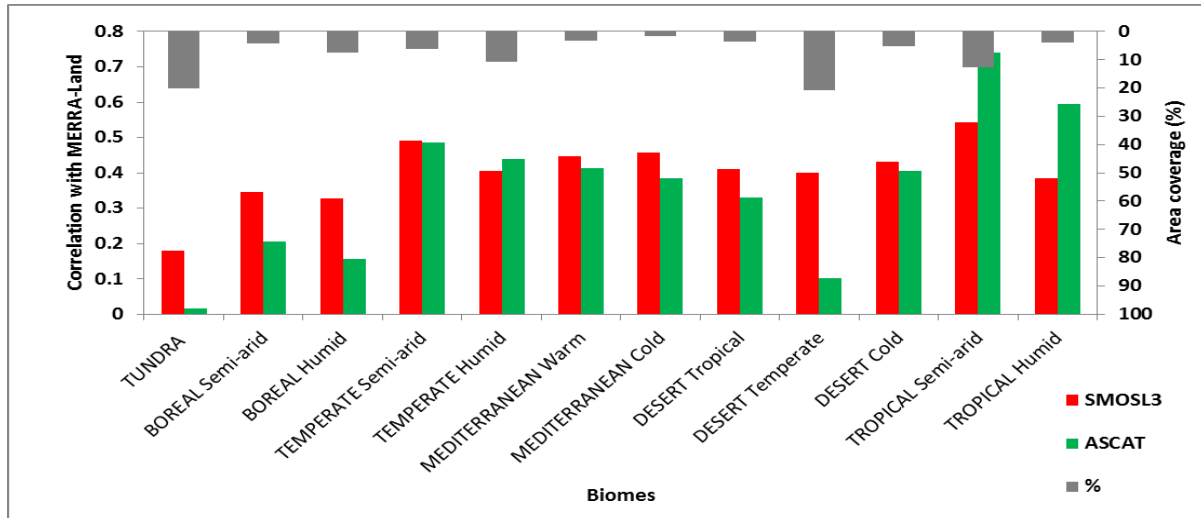

Fig. 4 Distribution of the correlation averaged by biome type between MERRA-Land and SMOSL3 (red) and ASCAT (green). The biome types are defined from the classification given by Chesworth (2008) shown in Fig. 1

The areas where SMOSL3 was closer to the reference than ASCAT (red), where ASCAT was closer to the reference than SMOSL3 (green) and where both ASCAT and SMOS are comparable i.e. difference in the R <0.05 (blue) are displayed in Fig. 3. Regions (e.g., Central Europe, China and India, with high contamination of RFI (RFI > 30%) are masked in grey.

Similar values of the R coefficient were obtained for both SMOSL3 and ASCAT over desert cold (R ~ 0.4), temperate semi-arid (R~0.5), Mediterranean warm, Mediterranean cold, desert tropical, and desert cold but big difference was found over desert temperate where ASCAT had a correlation value of 0.1 and SMOSL3 had a correlation value of 0.4.

4. CONCLUSION

SMOSL3 and ASCAT showed a good agreement in regions (e.g., Great Plains of North America, Sahel, Eastern Australia, etc.) that have a strong coupling between SM and precipitation (e.g., [28]). The effects of vegetation were useful to explain the compared performances of the SMOSL3 and ASCAT SSM products: both products have different sensitivity to vegetation [29, 30]. The present study revealed the high complementarities between SMOSL3 and ASCAT to monitor SSM and thus data fusion would be pertinent for climate change initiative (CCI). Finally, caution should be taken in these analyses: (i) MERRA-Land SSM estimates cannot be considered as "ground truth" and therefore the analyses are relative to the accuracy of the MERRA-Land product and (ii) current issues of the used versions of SMOSL3 and ASCAT SSM products are under investigation. As a next step of this study, advanced analyses such as the triple collocation technique may give different insights in the performances of both SMOSL3 and ASCAT SSM products.

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